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Current situation and prospect of China's geothermal resources

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ABSTRACT

At present, countries around the world set off a round of upsurge of exploitation and utilization of geothermal energy. As one of renewable energy resources, geothermal energy has the advantages of great resource potential, low carbon emissions, widespread distribution, easy development and so on. China's geothermal resources are enormous and have huge potential for exploitation. However, due to the lack of reasonable industry planning and policies support, and lag of technologies, the industrial development speed and scale are far behind the wind, solar and biomass energy. The 12th Five-Year Plan for National Economic and Social Development of the People's Republic of China explicitly issues that in future China will vigorously develop the geothermal energy and provide more policy support for geothermal industry development from medium to longer term. This paper describes China's geothermal resource potential and status quo of geothermal industry, and analyzes the obstacles of the industry development. Then, it accordingly puts forward the development pattern of China's geothermal industry and gives out related countermeasures. At last, it outlines the prospects in this field.

Contents

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1. Introduction

With the rapid development of economy and the need of the energy conservation and emissions reduction in China, the existing energy structure is no longer rational. Renewable energy development and utilization are gradually paid attention to by the whole society. As a kind of pollution-free energy, geothermal energy plays an important role in alleviating the pressure of energy supply and improving the ecological environment, which gets the favor of the government and enterprises [1].

On August 6, 2012, National Energy Board released "the 12th Five-Year Plan". According to the plan, the total development and utilization capacity of geothermal sources should reach 15 Mt standard coal by 2015. Among them, geothermal power installed capacity would reach 100 MW, shallow geothermal heating and cooling building area would reach 5×10^8 m^2 [2]. What is more is that China's geothermal sources are abundant. According to official figures released by China's Ministry of Land and Resources (MLR) recently, the total Hot Dry Rock (HDR) resources distributed at depths 3–10 km are equivalent to 2,60,000 times the capacity of annual energy consumption of China in mainland China. That is to say, the geothermal resources in China are equivalent to 8.6×10^{14} t of standard coal, which can be used about 2,60,000 yr for national consumption.

In the aspects of the development potential of geothermal resources, Guiling Wang et al. [3] assessed and summed up the resource potential in shallow, sedimentary basins, apophysis mountains and hot dry rocks (HDR, potentially for enhanced geothermal systems, EGS) in China by using different methods and models. Guiling Wang [4] summarized the main problem of exploration and evaluation of China's current geothermal resources and put forward the main tasks and work in future. Jiyang et al. [5] updated the heat flow map in the continental area of China on the basis of more new heat flow data, and then estimated the geothermal resources in the continental area (3–10 km). Kewen et al. [6] investigated and modified the methods of estimating geothermal resources coexisted in oil and gas field.

In the fields of development and utilization of geothermal resources, Xia [7] and Yanxia [8] believed some problems existed in China's geothermal industry, which included the low level of exploration and evaluation, lag of technologies, lack of the geothermal resources information management system, and some countermeasures have been proposed. Jinhua et al. [9] pointed out that only exploited in rational way, can geothermal resources be considered a kind of renewable energy, therefore, the sustainable development of geothermal resources are very important. Guiying et al. [10] systematically reviewed status quo, problems of China's geothermal industry and made recommendations. Melih et al. [11] indicated that Turkey's geothermal power installed capacity was expected to reach 500 MW by the year of 2021 subsequent to the implementation of "Renovation of Standards and Regulations" and "Fiscal Approaches".

Up to now, papers about China's geothermal lack the new data and systematization. This paper supplemented the newest data and systematically introduced the resource potential, the status quo of development and utilization, policy situation and the obstacles of geothermal industry in China. Finally the cooperation mode of "government–enterprise–university–research institution and application" was applied to provide theoretical references for the development of geothermal energy in China.

2. Geothermal resource potential

China is a large country with rich geothermal resources, in which low-medium temperature type occupies a major position. China's geothermal resources potential is tremendous, close to 8% of the total around the world. From 2009 to 2011, the MLR reappraised shallow geothermal energy of more than 287 local cities, geothermal resources of 12 main sedimentary basins and 2562 apophysis mountains in hot spring area, as well as HDR resources at depths 3–10 km. So far, the work has made some progress as shown in Table 1. Table 1 indicates that China's geothermal energy is mainly distributed in the sedimentary basins and the HDR.

From the point of resources distribution, geothermal resources in China cover all over the country, but the distribution is not balanced (Fig. 1). The high temperature geothermal resources mainly scatter in Tibet, Yunnan and Taiwan region. The low-medium temperature geothermal resources mainly distribute in the southeast coastal area like Hainan, Guangxi, Guangdong, Jiangxi, Fujian, Zhejiang as well as cenozoic large and medium sedimentary basins such as Sichuan, north China, north Jiangsu, Erdos and Songliao.

From the perspective of resources exploration and evaluation, there are 103 geothermal fields in China having been formally prospected and approved by the competent department of territorial resources at present. More than 2000 geothermal wells have been dug and 214 geothermal fields have been preliminary evaluated. In addition, the submitted B+C grade exploitable geothermal resources have reached 330 million m^3/yr and the D+C grade exploitable geothermal resources have reached 500 million m^3/yr [13].

3. The status quo of China's geothermal industry development and policies

3.1. Current situation

In the early 1970s, the world was facing the first oil crisis, and countries all over the world generally attached the importance to the development of renewable energy. China is one of the earliest countries that used geothermal resources in the world. Since 1990s, China's geothermal development and utilization have been booming driven by market demand [14]. At present, China has initially formed integrated development and utilization system of geothermal resources. It centers on power generation and direct utilization which includes heating and cooling, spa treatment, agricultural use, industrial production, etc. In addition, since hardly restricted by resources distribution, the utilization of shallow geothermal energy in China has developed rapidly in recent years, and then the technologies also became more and more mature. China's direct-use capacity of low-medium temperature geothermal resources per year has consistently ranked first in the world over the past 20 yr. The rank of capacity used by ground source heat pumps (GHP) in a short span of 10 yr has jumped to the second in the world just after the United States [15].

Table 2 illustrates China's geothermal power generation, direct-use (except for GHP) as well as GHP utilization in 2009. As can be seen from Table 2, China's GHP utilization occupies a very large component of the total geothermal, and has a promising future.

Table 1
Different types of geothermal resource potential [4,12].

Type	Resource potential (Mtce)	Annual available utilization (Mtce/yr)	CO_2 reduction in potential (Mt)
Shallow	9500	350	500
Main sedimentary basins	8,53,000	640	1300
Apophysis mountains		23	59
HDR	86,000		

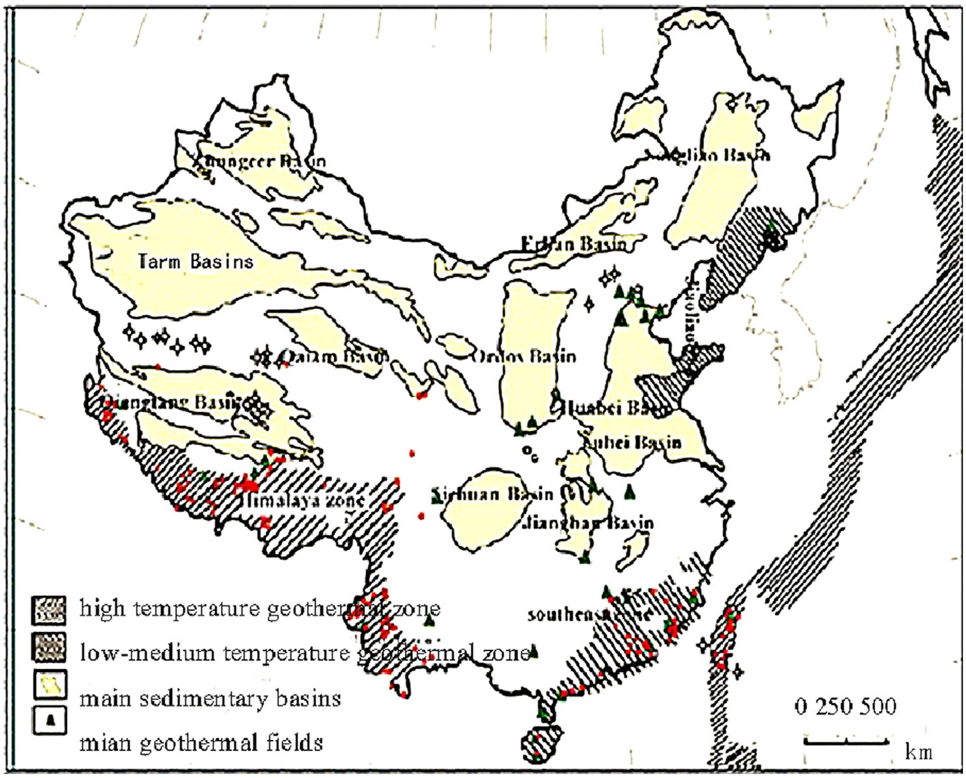

Fig. 1. Distribution pattern of China's geothermal resources.

Table 2
China's geothermal utilization in 2009 [16].

Type	Area (h m^2)	Equipment capacity (MW)	Annual use (TJ/yr)	Total production (GWh)	Standard coal (kt)
Power generation		24	517	144	47
Direct-use (except for GHP)	3020	3687	46,313	12,865	2630
GHP	10,070	5210	29,035	8065	1650
Total	13,090	8921	75,865	21,074	4330

3.1.1. Geothermal power generation

Geothermal power generation can be divided into conventional power generation and enhanced geothermal systems (EGS) power generation. Conventional type in China is usually divided into high temperature (above 150 °C) geothermal power generation and low-medium temperature geothermal power generation. Traditional geothermal power generation appeared relatively early in China compared to EGS. It has fairly sound technical foundation while the EGS power generation is still at the stage of project research, development and demonstration (RD&D) currently. According to the research, geothermal power generation is far more cost-effective than geothermal direct-use. The energy utilization coefficient of former is up to 73% on average, and the latter only reaches 23%.

3.1.1.1. Conventional power generation. According to statistics, China's total high temperature power generation potential is 2781 MW, and quasi high temperature geothermal potential is 3036 MW. In the late 1970s, China began to apply high temperature geothermal resources for electricity generation and geothermal power plants are established successively in Tibet Yambajan, Langjiu and Naqu. According to national report of 2010 world conference on geothermal energy, only Yambajan thermal power plant was still on, other four plants in Tibet and Taiwan were shut down due to scaling problems [17].

China has built seven low-medium temperature geothermal power plants across the country, and successively accomplished tests successfully. They were built in: Deng Wu of Guangdong (92 °C, 300 kW), Huitang of Hunan (98 °C, 300 kW), Haoyao of Hebei (87 °C, 200 kW),

Table 3
Comparison of four geothermal power generation technologies [20].

	Dry stream	Expansion-style steam	Dual-working medium cycle	Kalina cycle
Matched geothermal fields	High temperature ($t > 250$ °C)	High-medium temperature (130–250 °C)	Low-medium temperature ($t < 130$ °C)	Low-medium temperature ($t < 90$ °C)
Generation efficiency (%)	Exceed 20	15–20	35–50	40–50
Corrosion and fouling	Only a small amount of polluting gases	Serious	No	No
Equipment of power system	Simple system	Simple system	Complex system	Complex system
Operation and maintenance cost	Low	Low	High	High
Environmental impact	Little impact with good recharge technology management	Little impact with good recharge technology management	Some impact with the use of organic working medium	Some impact with the use of ammonia–water mixture

Zhaoyuan of Shandong (98 °C, 300 kW), Xiongyue of Liaoning (90 °C, 200 kW), Xiangzhou of Guangxi (79 °C, 200 kW) and Shuichuan of Jiangxi (67 °C, 100 kW) [18]. Until the late 1970s, except for the previous two power plants, the rest five were closed. In recent years, with the progress of technology, low-medium temperature geothermal power generation is "coming back to life". Especially in the deep of large and medium sedimentary basins coexisted with oil and gas fields, a lot of low-medium temperature geothermal resources are available for exploitation and utilization [19]. Huabei oilfield completed a 400 kW model geothermal power plant of oilfield low-medium temperature underground water at the end of last year.

There are four main geothermal power generation technologies: dry stream, expansion-style steam, dual-working medium cycle (we call it Organic Rankine Cycle, ORC) and Kalina cycle. We draw a comparison among them in terms of matched geothermal fields, generation efficiency, corrosion, fouling and so on. From Table 3, you can see, the former two types are suitable for applications in high-medium temperature or high temperature geothermal fields, and they have simple systems, low operation-maintenance cost and little impact on environment. The latter two types are suitable for applications in low-medium temperature geothermal fields, and they have high efficiency and no corrosion or fouling.

Expansion-style steam technologies or ORC were used in the low-medium temperature geothermal power plants above [18]. Unit 2 in Tibet Yambajan power plant used the dry steam generation technology, the power of which is 3 MW. The inlet steam pressure is 0.56 MPa and the inlet temperature is 160 °C. Units 3–9 in Tibet Yambajan power plant mainly applied the secondary expansion-style steam. The initial inlet steam pressure is 0.65 MPa, and the steam flow is 22.7 t/h. The secondary steam inlet pressure is 0.45 MPa and the steam flow is 22.6 t/h. Yambajan power plant also built up an 800 MW dual-working medium circulating screw expanding unit by using recovered geothermal water in 2008. The internal efficiency of such power generation systems has reached up to 79–80% [20]. When its load has a big change in range, its performance indicators fluctuate quite small. In addition, its equipment inlet design parameters are matched to that of geothermal energy resource and it is the best geothermal power generation mode at present [13].

So far in 2011, the only electric production is from the Yangbajain field in Tibet (24 MW). The installed capacity of geothermal power plants is shown in Fig. 2, which displays that geothermal power generation in China has been stagnant for 30 yr. It was known that a 2500 m deep well was drilled in 2004, reaching the deep reservoir. Temperatures in the 250–330 °C range have been measured at 1500–1800 m depth. Zheng et al. [21] had good expectations for it, and pointed out that both the installed capacity and produced electricity would increase by a large margin.

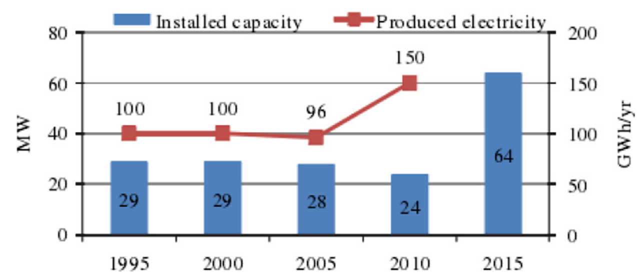

Fig. 2. Installed capacity and produced electricity in China [21].

3.1.1.2. Enhanced geothermal system. The merits of EGS (or HDR) power generation are its huge deposits, high efficiency, stable system and little effect on the environment. Taking advantage of EGS, people can economically exploit deep geothermal energy from low permeability rock mass at depths 3–10 km underground. It is the mainstream way of using geothermal energy in the world now.

EGS has a certain cost advantages. The cost of EGS power generation is now 2.72 yuan/kWh, according to the evaluation after the tests conducted by the United States and Australian. If the localization of the geothermal drilling technology in China comes true, the investment cost of geothermal power generation in China is close to wind power and far less than solar power according to its actual utilization rate 3–4 times the much of wind energy. In addition, the cost of geothermal drilling will decrease considering the current development trend of the oil drilling technology. Therefore, once a breakthrough happens in the EGS, the application prospect will be more competitive either than wind energy or solar energy.

United States, Britain, Japan, Switzerland, Sweden, Australia, Germany, France and other countries had a research history of more than 30 yr. Moreover, some countries were committed to shale gas exploration and development which was similar to EGS in the development technology. The key technologies of shale gas development including horizontal well technology, fracturing technology that could be directly transferred to the geothermal resource development [5].

However, development research of the high temperature rock geothermal started late in China, and only a handful of scientific research institutions did the theory discussion and participated in the HDR or EGS international cooperation (Table 4) [22]. As can be seen from Table 4, China's upfront input was small. It mainly focused on academic exchanges and research while the technology research bases and equipment conditions of national level have not formed. However, at the late stage, China increased exploration and project investment. The support of government and the progress of the project provided technology accumulation as well as opportunities for the development.

3.1.2. Direct-use applications

China's geothermal direct-use concentrates on heating and cooling, spa treatment, agricultural use, industrial production, etc.

Table 4
Research on EGS development and utilization [22].

Year	Research or project	Contents
1993–1995	China Seismological Bureau Crustal Dynamics Institute cooperated with Japan Central Power Research Institute	Did research on HDR power generation in Fangshan, Beijing
2000	A research team led by professor Zhao Shengyang	Started researches on development of high temperature rock geothermal energy, presented the EGS technologies systematically
2007	China's Energy Research Association Geothermal Professional Committee conducted an international project "research on Chinese EGS potential" with Australian firm "Petratherm"	Did the basic investigation of the area that are potential of EGS, collected some test samples, and accomplished works such as a series of model researches
2009	Daqing government held a forum for the city's new energy	Pointed out that geothermal Energy of Daqing is rich, distributed in the area of 5000km^2. The HDR energy at the depths from 4000-5000m is equivalent 10000 times the capacity of gas and oil in this city
	China's Geothermal Professional Committee made up an expedition team with Geological Environment Monitoring	Inspected Australian HDR energy in Cooper basins developed by the firm "Geodynamics"
2011	Guangdong Geological Bureau held a seminar about feasibility of deep geothermal exploration	Defined deep high-temperature geothermal resources as energy resources in order to distinguish it from the domestic extensive spa bath at present
	Related units of Tianjin and Hainan assessed the local enhanced geothermal resource	Prepared to study on the feasibility of EGS
2012	"863 Planning" started the project of "research on key technologies of energy development and utilization"	Provide a chance for the development of EGS technology and a support for the engineer utilization in the future

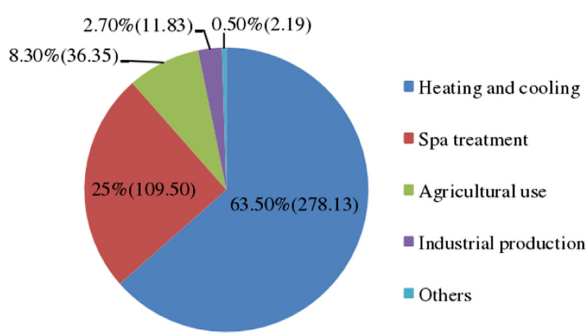

Fig. 3. Direct-use structure and absolute values (PJ/yr) of China's geothermal energy.

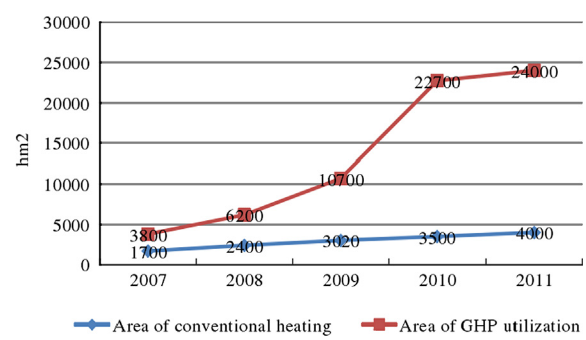

Fig. 4. China's geothermal heating and cooling area [9,23].

Meanwhile, the stepped utilization technology, the energy storage technology of underground aquifer also gradually developed. In 2010, China's direct utilized heat was 438 PJ/yr [17]. Fig. 3 displays that the main patterns of China's low-medium temperature geothermal direct-use are heating (cooling) and spa treatment, which accounted for about 90% of all. Especially, 49% of the total utilization is GHP heating.

3.1.2.1. Heating and cooling. China's geothermal heating and cooling application developed significantly, now it formed a certain industrial scale. GHP in China developed in 2004. Since more practical and more energy saving than direct heating, the market recognition of GHP increased year by year. In 2004, the area of national GHP heating (including cooling) was only 7.67×10^6 m^2, but increased to 2.035×10^7 m^2 in 2006. In March 2011, China applied 2236 shallow geothermal heating and cooling construction projects and 80% of which concentrated in Beijing, Tianjin, Hebei, Liaoning, Henan, Shandong and so on [12]. Just in Beijing, the area of shallow geothermal heating and cooling buildings have already reached about 3×10^7 m^2, while in Shenyang, the area is more than 6×10^7 m^2. On March 8, 2012, the first domestic but also the world's first geothermal heating CDM project was born in China Petrochemical Corporation. This project was the result of 4 yr by Sinopec Green Energy Geothermal Development Co., Ltd. During the "12th five-year", China is expected to complete 3.50×10^8 m^2 GHP heating (including cooling). Considering the investment strength of 200–300 yuan[1]/m^2, the total investment can reach 70–105 billion yuan.

In recent years, China's development in geothermal heating and cooling applications is as shown in Fig. 4. It can be seen from Fig. 4, China's geothermal heating and cooling developed very rapidly, and it came from behind. Conventional geothermal heating area was 4000 h m^2 in 2011, which was 2.3 times of 1700 h m^2 in 2007, and the average growth rate was about 23% per year. While the heating (cooling) area of GHPs, which developed fast from 3800 h m^2 in 2007 to 24,000 h m^2 in 2011 with an annual growth rate of 58%. What's more, the cost of GHP systems installation also dropped dramatically at the same time from the original 400–450 yuan to the current 220–320 yuan. And the public awareness of GHP has greatly improved. Thus, the prospect of GHP seems to be better compared to traditional heating.

3.1.2.2. Spa treatment. Hot spring resources in China is very rich and all over the country (Table 5), they are geographically concentrated in Beijing, Liaoning, Shandong, Fijian, Guangdong, Yunnan, Sichuan, Chongqing, Tibet, Hainan, Taiwan and other provinces or cities. Till now China has found about 4000 hot water points (including hot springs, drilling and mine water) that the water temperature is above 25 °C. Hot springs exposed in

[1] Exchange rates: $1 = 6.0496 yuan. The further occurrences will be the same.

Table 5
Distribution of China's main geothermal hot springs.

Area	Hot spring distributions
Northwest	Huaqing Hot Spring, Guide, Tianshui Jieting, Yanjinhe, Bulong
Northeast	Anshan Tanggangzi, Five Lotus Ponds, Arxan Shengquan, Fusong, Changbai Mountain, Lotus Hill
North China	Dragon, Jiuhua, Fengshan, Chunhui Garden
Central China	Chenzhou paradise, Chenzhou Rucheng, Zhangjiajie Wanfu, Zhangjiajie Jiangya, Han Xianning, Xianning Changyin, Scarlett turned River Wetland, Yingcheng Tangchi, Yanling Huadu
East China	Hasan, Tangshan, Lianyungang Donghai, Wuyi Tang Feng
South China	Enping Imperial, Enping Jinjiang, Yangjiang, Qingyuan Xinyin lamp, Conghua Bishuiwan, Zhuhai Royal, Guantang, Guiling Longsheng

Tibet, Yunnan, Guangdong, Fijian and Taiwan account for more than 50% of the total throughout the country. They were followed by Liaoning, Shandong, Jiangxi, Hunan, Hubei and Sichuan provinces, and the spa number is above 50 in each province. In the field of spa treatment, the focus was gradually transferred from traditional bath to health care and leisure entertainment, which embodied the humanization and spa culture connotation.

3.1.2.3. Agricultural use. China's geothermal energy applied in the agriculture has developed in the integrated direction, mainly concentrates on geothermal greenhouse planting and aquaculture. Meanwhile, technologies such as irrigation, poultry incubation, vegetables drying, marsh gas tank heating and animal bathing pool heating also develop rapidly.

It is very suitable to use geothermal energy for anti-season biological cultivation, since geothermal energy can heat greenhouses, and geothermal water with minerals can also provide nutrients for life. In different parts of China, the agricultural use of geothermal resources is different. In northern China, it is mainly used for planting high-grade fruits, vegetables, edible fungus, flowers, etc. while in the south, it is mainly applied in rice seedlings. Till now, China's geothermal cultivation has achieved a certain scale and technology level. According to statistics, the current total area of geothermal greenhouse is 1.33×10^6 m^2. Glass geothermal greenhouses with a single-house area of 2–3 $\times 10^4$ m^2 have been built in Beijing and Tianjin which are automatic controlled by temperature and humidity, and they have reached the international advanced level. At present, the capacity of geothermal greenhouse in China is equal to 2,15,000 t of standard coal, which accounts for 3.4% of the total geothermal resources exploited per year.

Geothermal aquaculture is one of the main fields of geothermal agricultural use in China. Beijing, Tianjin, Fijian, Guangdong and other places started earlier, and now geothermal aquaculture covers more than 47 geothermal fields in 20 provinces (autonomous regions, cities), in which there are about 300 farms and 4.45×10^6 m^2 of fish ponds. The water consumed by aquaculture is about 5.7% of the total geothermal water consumption, which are used to breed tilapias, eels, soft-shelled turtles, freshwater shrimps, bullfrogs, etc., and help fries live through the winter [16].

3.1.2.4. Industrial production. Currently, geothermal industry mainly focuses on textile printing and dyeing, washing, leather and paper making, lumber and grain drying. Some industrial raw materials can also be extracted from parts of the geothermal water. For example, Tengchong Atami Sulfur Pond uses elutriation method to get sulfur. And Eryuan Jiutai hot spring area digs up glauber's salt and natural sulfur. Huabei Oilfield applies the deep ordovician in sealed oil wells to pipe oil with geothermal water, entirely replaces the method of piping oil with boiling hot water, which has achieved obvious economic and social benefits [16]. The technologies of industrial use are becoming more and more mature and gradually promoted all around the country.

3.2. Policy situation

3.2.1. Policy and regulations

In order to guarantee the development of geothermal industry, Chinese government has formulated a series of policies and regulations (Table 6). Table 6 displays that China gradually paid attention to geothermal energy, and more and more detailed policies and regulations were proposed. “Renewable Energy Law”, “The Decision of the State Council on Energy Saving”, “Comprehensive Working Program on Energy Saving and Emission Reduction” and “Ordinance on Civil-building Energy Conservation” just propose to attach importance to the development and utilization of geothermal energy, and have no detailed orders.“Technical Code for Ground Source Heat Pump Systems”, “Notice of the Ministry of Construction and the Ministry of Finance on the Implementation Comments for Application of Renewable Energy in Building” and “Interim Measures for Management of Special Found for Applications of Renewable Energy in Buildings” point out that technology supports and fund aids should be provided for the geothermal industry. “Interim Measures of Ningbo for usage Management of Special Fund for Energy Conservation and Clean Production”, “Guidance on Heat Pump System Development”, “Notice on the Promotion of Shallow Geothermal Energy Development and Utilization”, “Shenyang's Plan for Promotion and Development of Ground Source Heat Pump”, “Interim Measures of Chongqing for Management of Special Allowance for Application Demonstration Projects of Renewable Energy Buildings” and “Interim Measures of Shanghai for Management of Special Allowance for applications of Renewable Energy Buildings” specify allowance for geothermal industry. However, we can see most of the policies or regulations are just something of framework or slogans and hard to be implemented in practical application. Although some subsidy policies were proposed, only a few cities such as Ningbo, Beijing, Shenyang, Chongqing and Shanghai are covered by the allowance.

3.2.2. Development goal

In July 2012, “the 12th Five-Year Development Plan for Renewable Energy” was issued that the annual use of renewable energy to 2015 would reach 478 million t of standard coal, and the construction heating and cooling area of shallow geothermal energy is to be 500 million m^2 which can provide heating water for 1.2 million homes.

The utilization structure of renewable energy is displayed in the plan (Fig. 5a). The figure shows the amount of geothermal energy development and utilization only accounts for 3.14% of the total renewable energy, which equals to 15.01 million tons of standard coal. The plan also indicates the investment demand estimation of total renewable energy is about 1800 billion yuan, in which the investment of geothermal and solar water heaters use is approximately 80 billion yuan. Just like Fig. 5b shows that the geothermal energy accounts less than 4.4% in the proportion of

Table 6
Industry policies for China's geothermal energy.

Time	Law or regulation	Contents
2004.12	Interim measures of ningbo for usage management of special fund for energy conservation and clean production	An allowance equivalent to 20% of the actual investment will be provided to the project.
2006.1	Renewable energy law	Lists geothermal energy development and utilization into the scope of encouraged new energy development
2006.1	Technical code for ground source heat pump systems	Provides specification for the design, construction and acceptance of ground source heat pump system projects and ensuring safe and reliable system operation
2006.7	Guidance on heat pump system development	A one-time allowance of 50yuan/m^2 has been granted to ground source heat pump projects under construction within this area.
2006.8	The decision of the state council on energy saving	Proposes to make great efforts in the development of renewable energy source, including wind, solar, biomass, geothermal and water energy
2006.8	Notice of the ministry of construction and the ministry of finance on the implementation comments for application of renewable energy in building	Lists ground source heat pump application among key technological fields
2006.9	Interim measures for management of special found for applications of renewable energy in buildings	Lists the ground source heat pump as a key field to be supported, with financial assistance provided to projects meeting relevant conditions
2007.6	Comprehensive working program on energy saving and emission reduction	States that the energy structure adjustment and the scientific research development and construction of building integrated with geothermal energy shall be actively promoted, and the resource investigation and assessment shall be enhanced
2007.8	Shenyang's plan for promotion and development of ground source heat pump	Specifies that for projects using GHP, the system power consumption will be charged at a favorable rate, the charge for water resources will be exempted, and they can also take advantage of all preferential policies provided by the government for any area using coal-fired heating
2007.10	Interim measures of chongqing for management of special allowance for application demonstration projects of renewable energy buildings	Proposes to provide allowance of 800–900 yuan/kW for systems used for renewable energy buildings
2008.8	Ordinance on civil-building energy conservation	States that China encourages and supports geothermal energy application
2008.12	Notice on the promotion of shallow geothermal energy development and utilization	Makes deployment for the promotion of survey assessment, development and utilization planning and monitoring of shallow geothermal resources
2012.9	Interim measures of shanghai for management of special allowance for applications of renewable energy buildings	Provide allowance of 60 yuan/m^2 to the maximum for the two and three star demonstration projects. The subsidy for individual project is up to 60 million yuan and for affordable housing projects is up to 10 million yuan
2013.1	Notice on the promotion of geothermal energy development and utilization	Sets a goal for geothermal energy development and utilization in 2015 and 2020, refers to the key tasks and subsidy policies

total investment demand, which is only 79.2 billion yuan. Seen from the two figures, the support effort of China's policy to the geothermal industry is less than hydro, wind and solar energy industries. Especially, the 100 MW capacity of geothermal power generation is only equivalent to the unit capacity of current eliminated coal-fired power, and it impacts little to domestic energy structure [24].

According to the 2030 National Energy Strategy Research Report of Scientific development, the proportion of geothermal energy in the renewable energy will increase to 4.4% in 2020, 5.2% in 2030 and 5.5% in 2050. As to geothermal power generation and direct-use, China Academy of Engineering puts forward the development goals in different time nodes (Table 7). As can be seen from Table 7, up to 2050, the scale of the low-medium temperature geothermal direct-use will be three times of that now, and the shallow geothermal energy utilization can reach 50,000 MW t. The high temperature power installed generation capacity will be promoted, and stress will also be put on the development of the low-medium temperature and the EGS power generation.

4. Obstacles of development

4.1. Lack of systematical investigation and exploration

First of all, climate conditions, geological conditions, technology standards, environment response.et al. influence deeply on the development and utilization of China's shallow geothermal energy. However, there is no systematic research on it. Not enough emphasis was put on the investigation and exploration of geothermal resources, which resulted in lacking exploration in most regions of China. Especially, in the western China, the basic exploration of low temperature geothermal resources has not been carried out. Moreover, geothermal resources information database has not been set up for the shortage of unified geothermal resources information system and the low level of management automation [4].

4.2. Shortage of specific policy support

Geothermal industry chain is long, and much money should be invested from the beginning to the end in geological exploration, product research and development, manufacturing, system installation, after-sales service, etc. For enterprises, the investment risk would be high and the enthusiasm may be impeded if there are few policies to support investment. Although geothermal heating and GHP industry have been supported by national polices, subsidies is not widely enough. Only some cities like Ningbo, Beijing, Shenyang, Chongqing and Shanghai have clear subsidies standards for the GHP.

What's more, the geothermal power generation industry almost got no support from the government for nearly 30 yr [26]. According to “the Study of Security Conditions for Development of Renewable Energy Resources”, the operating cost of China's geothermal power generation is estimated at about 0.4 yuan/kWh. However, if the cost of resource survey and well drilling is taken into consideration, the total generation cost will reach more than

1.0 yuan/kWh. It leads to competitive disadvantage for geothermal power generation when either compared with the traditional generation or other new energy power generation like wind power and photovoltaic power which enjoy national subsidy policies. In 2013, according to the renewable energy electricity price additional policies, "Notice on the Promotion of Geothermal Energy Development and Utilization" for the first time issued to subsidies to the geothermal power generation projects, but there are no corresponding standards of subsidies.

4.3. Lag of technologies

There is a gap between China and the other countries in geothermal technologies. As for conventional power generation, geothermal wells process, recharge, corrosion and fouling treatment cannot be handled well. For this reason, China's installed capacity of geothermal resources has kept 25 MW, which ranked 18 among 24 geothermal power generation countries all around the world [17]. The main problems of low temperature geothermal power generation are the low efficiency and the need of some special techniques such as dual-medium power generation. Thus the feasibility of technologies and economy is questionable. What is more is that China's EGS only stays at the stage of RD&D at present for the late start though it has huge resource potential.

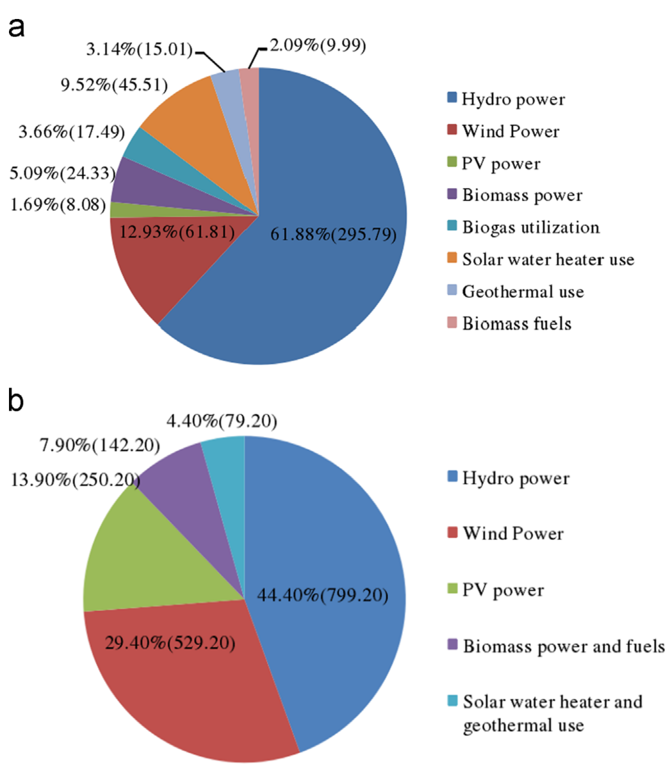

Fig. 5. (a) Utilization structure and absolute values (Mtce) of renewable energy [24]. (b) Stucture and absolute values (billion yuan) of renewable energy investment estimation [24].

Recharge and stepped utilization technologies are not widely applied in the large scale development of geothermal direct-use for the complex process. Therefore, problems of lower utilization efficiency and environmental pollution arise.

4.4. Extensive development and utilization

China's geothermal industrial structure and the way of using resource are unreasonable at present for the low level of exploitation and utilization. What is more is that the phenomenon of ignoring management can be seen everywhere, and economic benefits of the whole geothermal development are limited.

Many geothermal enterprises just aimed to gain high profits and completely ignored energy-saving and environmental protection. Thus, they applied single developmental model with extensive management instead of using geothermal comprehensively, which wasted geothermal resources. For example, the heat energy utilization rate of geothermal wells that applied direct supply-discharge style of heating ways was only 20–30%, which led serious resources waste.

Currently, geothermal wells in some districts were too concentrated, and intensive exploitations were conducted currently. Both of them resulted in the decline of geothermal water, which influenced the stability of long term exploration, and caused land subsidence. In Tianjin Tanggu and Dagang, the geothermal exploitation caused land subsidence of about 6–10 mm/yr. What is worse is that groundwater pollution, chemical pollution and other environmental problems also appeared.

5. Advices of development mode and measures

5.1. Development mode

According to analysis above, China's geothermal resource potential is huge. With the support of policies, the prospect of geothermal energy seems to be bright. But currently, there are some problems in this industry from resource exploration, policies support, technologies application to comprehensive utilization of resources. In order to solve these problems, many participants should be involved in cooperation, including the government, enterprises, universities, research institutions and consumers.

Thus this study introduces the innovative cooperation system of "government–enterprise–university–research institution and application" [27]. This mature model provides beneficial enlightenments for China's geothermal industry (Fig. 6). In order to solve problems in the way of developing geothermal industry and accomplishes the industry goal innovatively, it suggests that the dominant role of the government should be developed. And it also suggests strongly that the connection among the innovative principals should be strengthened and the combined forces for cooperation and innovation be formed.

The word "government", means that geothermal development should be led and promoted by the government. The duty of the government is to build innovation platform and issue related policies to promote the development of industry integration.

Table 7
Strategic targets of geothermal energy development in China [25].

Year	Power generation/MWe			Direct-use/MWt	
	High temperature	Low-medium temperature	EGS	Low-medium temperature	Shallow geothermal
Status quo	25.18	0.5	–	3239	3000
2020	75	2.5	Experiment	4000	10,000
2030	200	20	25	6500	20,000
2050	500	100	200	10,000	50,000

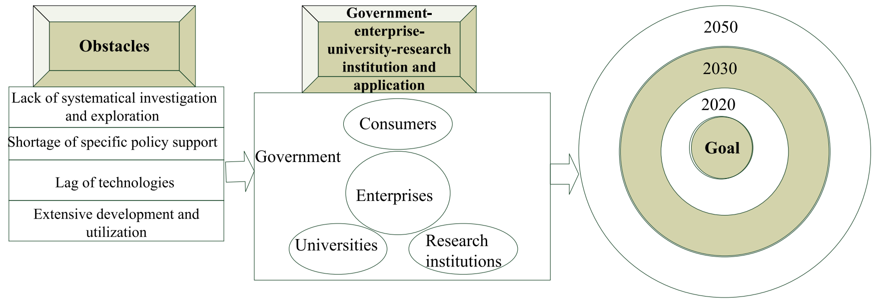

Fig. 6. Cooperation mode for China's geothermal industry.

A strong government can provide a good market environment to ensure the cooperation of enterprises, universities and the research institutions. Thus it can accelerate the transfer of technology and the realization of innovation value which will strengthen the potential development of geothermal industry.

"Enterprise–university–research institution" is the core of the mode, which indicates enterprise, university, research institution are the innovative and cooperative principals. The output of research institutions and the personnel of universities are considered as the motive force for the enterprise development. At the same time, enterprises provide part of the funds for research institutions to do research and universities to train personnel. Its essence is to promote the combination of technology, education and economy.

"Application" here mainly focuses on consumers. If consumers participate in the industry and give demand feedback actively, which cannot only reduce the blindness of technology innovation to shorten the time of technology transfer, but also can effectively reduce the risk of technological innovation.

5.2. Specific measures

In the mode of "government–enterprise–university–research institution and application", government plays an important role in guiding and supporting geothermal industry in all fields to establish a good market environment. This study will give proper advice in four aspects as below.

5.2.1. Explore and evaluate geothermal resource deeply and thoroughly

China's geothermal exploration and evaluation lag behind the development and utilization. At present, the most important thing is to establish a national research platform to incentive enterprises and research institutions to participate in the exploration and evaluation work. To start with, the government should set the exploration and evaluation targets in detail, and assign the tasks to the relevant departments in each area. Then, unified standards for the methods of exploration and evaluation should be issued and published on the public platform timely. Furthermore, an information monitoring system ought to be constructed according to distribution and utilization potential of resources in every region, so as to guarantee the sustainable development and utilization of geothermal resources. Last but not the least, a model of feasible resources utilization on the basis of corresponding exploration data is needed, which is to provide foundation for the development plan of geothermal industry.

5.2.2. Plan the development and utilization of geothermal resources reasonably

It is necessary to save geothermal energy when develop it. The words of "develop in the protection and protect in the development" is just to the point. First of all, according to the model of geothermal resource utilization mentioned above as well as energy conservation and emissions reduction targets, the government must clearly define the ratio of geothermal resources in all energy utilization and the proportion of different types in the whole geothermal resources consumption. Moreover, development measures should be varied in different areas to coordinate the local government development planning. In Tibet, Taiwan, the government can focus on reforming the exited geothermal power plants to enhance or restore the power capacity. While in east China, 1–2 typical areas could be chosen to establish demonstration projects of low-medium temperature geothermal power generation by the way of attracting investment or inviting bids. And in north China, the emphasis is to promote the concentrated development of geothermal heating in order to economically meet the demand of avoiding cold weather. Whatis more, the blind, excessive investment on the project should be replaced by comprehensive utilization.

5.2.3. Create good policy environment

The government has better clearly specify the support standards and provide policy support extensively since the initial investment of geothermal industry is large. Special funds, subsidies, investment tax rebates or tax reduction to lower enterprises' cost in the early period of the industry development should be implemented. However, considering the sustainable development of the geothermal industry, these support measures should be appropriate and timely. The projects that are conducive to sustainable development and emissions reduction can obtain support, while the extensive management and pollution projects ought to be even rectified. Whatis more, measures have to be varied at different stages of the industry development. At the beginning, policy should be emphasized to promote industry development on a large scale. Then the key task is introducing competition mechanism in order to make geothermal industry be more independent and competitive gradually.

5.2.4. Promote technology innovation and improve the technical support system

Due to the immature technology, China's geothermal industry is still at the stage of extensive management, which is far from sustainable development. Thus, firstly, it is recommended that the government put the effective use of geothermal resources into the scientific research plans, and increase budget for it. Secondly, technology innovation founds should be set up to encourage enterprises make an alliance with research institution and universities to solve problems more quickly in the industry chain. At the same time, government and enterprises have better actively cooperate with abroad, and absorb the advanced technologies such as EGS power generation, recharge and oilfield associated technology. Finally, enterprises that apply comprehensive utilization

technology should be rewarded in order to realize sustainable development and environmental protection.

5.3. Advices of development of future technologies for geothermal use

The future technologies for geothermal use could be considered according to the resource conditions and regional differences of China's geothermal energy.

Pay attention to the geothermal resources of oil and gas area, and make full use of the hot oil, gas and water to recycle the heat. Focus the national advantage technology on the EGS, and carry out the test in a couple of favorable exploration area. For high-temperature resources, the innovative combined cycle power generation technology and comprehensive cascade utilization system are the development trend. The expansion-style steam systems can be used in the high-temperature phase of geothermal resource while the dual-working medium cycle or Kalina cycle could be applied when the resource temperature is not high enough. Then the resource can be used for heating and drying agricultural products. When becoming cooler, it can be applied in greenhouse planting, aquaculture and spa treatment. At last, the GHP systems can increase the resource temperature and send it back to the stage above. It is aimed to improve the efficiency of geothermal power cycle. For low-medium temperature resources distributed in a wider region, low-medium temperature geothermal power generation technologies such as Kalina cycle systems could be developed, and great effort will be made for direct utilization of geothermal energy.

In cold areas, geothermal heating supply will be promoted. In hot and damp south regions, direct geothermal utilization technology will be developed to meet daily life requirements including cooling of air-conditioner and preparation of bath in summer. In areas with abundant agricultural products, geothermal water can be used for drying products to obtain better economic benefits. In the north region and Jianghuai area with two distinct seasons, technology of combined heating, air-conditioning and hot water of GHP should be encouraged. In the south region, most attention must be paid to promote the application of combined cooling and heating system of the GHP to select low-medium buildings and villas satisfying requirements. [13]

6. Conclusion and prospects

While some obstacles need to be addressed, it is believed that China has bright prospects of geothermal development for the reasons below:

China is a big country with main geothermal resources at low or medium temperature, and it has a great potential and a bright future for shallow geothermal utilization. China's geothermal resources potential is tremendous, close to 8% of the total around the world. For the market of GHP alone, the current sale has exceeded 8 billion yuan, which is still growing at a rate higher than 20% per year. Moreover, the demand of the GHP has risen greatly with the significant decrease of initial installation fee to 220–320 yuan/m^2 of building area. During the 12th Five-Year Plan, China is expected to complete the GHP heating (cooling) for an area of about 3.50×10^8 m^2, when the total market of geothermal energy development and utilization will be at least 70 billion yuan. In the field of spa treatment, hot spring resources in China is very rich and all over the country. The focus of hot spring was gradually transferred from traditional bath to health care and leisure entertainment. What is more is that the technologies of agriculture and industrial use are becoming more and more mature and gradually promoted all around the country.

Chinese government considers energy conservation and emission reduction as a national development strategy. It attaches great importance to the utilization of renewable energy and the policy environment for geothermal development is better and better. The 12th Five-Year Plan expressly states that non-fossil energy will occupy over 15% in the future energy structure. On September 12, 2013, the State Council promulgated “the Atmospheric Pollution Prevention Action Plan”. It put the development and utilization of geothermal energy to the top position for the first time [28].

China increased emphasis on the research of geothermal development and utilization. On November 29, 2013, the Geothermal Resources Survey Research Centre of China Geological Survey was established in Shijiazhuang, Hebei. This is the first national research institution in geothermal fields. The center will carry out the investigation and evaluation of geothermal resources, do research on key technologies of exploration and establish demonstration projects for the development of shallow geothermal energy and HDR. It aimed at providing support for China's energy production and consumption, renewable energy development and national energy security.

It is also predictable that, with the deeply and thoroughly exploring and evaluating of geothermal resource, and the rapid progress of geothermal energy utilization technologies, the geothermal energy utilization will take a more important position in energy utilization for China's future and will surely has a wilder application prospect.

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